A MODEL FOR THE BURNING OF A HORIZONTAL SLAB OF WOOD: STATUS REPORT

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We are in the process of developing a burning-rate model for char-forming materials. Currently, the combustion of a horizontal slab of wood, exposed to an external radiant source, is being modeled in terms of two coupled sub-models which simulate gas and solid (condensed) phase processes. Although there are still problems with the solid-phase model, the results to date are encouraging.

Gas Phase Model: The algorithm which is used to model the gas phase phenomena has been described previously (Hamins et al., 1992). It is a simple global model which predicts the mass burning flux for pool fires burning in a quiescent environment. The model assumes constant bulk properties such as flame temperature, soot volume fraction, and species concentrations. The computational procedure requires knowledge of the combustion properties of a fuel (the radiative heat loss fraction, the combustion efficiency, and a characteristic soot volume fraction in the flame) and fuel properties such as the stoichiometry, heat of vaporization, heat capacity, and boiling point. The combustion properties can be characterized by a single variable, the smoke point height of the fuel (Tewarson, 1988). The smoke point can also be correlated to a characteristic soot volume fraction for a pool fire.

For simplification, this model treats wood as a single component fuel, with the gas phase combustion properties invariant as a function of time after ignition.

An average component-weighted heat of combustion for Douglas Fir was found to be 12.6 kJ/g. This is in contrast to the bomb calorimeter results which yield values from 17 to 22 kJ/g for air-dried soft woods (Domalski et al., 1978). The bomb calorimeter heat of combustion results vary strongly with water content and can be as low as 5 kJ/g (Domalski et al., 1978). Cone calorimeter measurements (described below) gave a 12 kJ/g heat of combustion for the conditioned Douglas Fir sample. Thus, the combustion efficiency χ_a can be estimated as $\chi_a \approx 12/12.6 = 0.95$.

The radiative heat loss fraction χ_r and f_v were estimated using the relationship between the combustion properties and the smoke point (Tewarson, 1988). The smoke point height of wood (estimated as 16 cm) and χ_r were determined using Tewarson's correlations (1988) and f_v was estimated from pool fire results (Bard and Pagni, 1981) as a function of the fuel smoke point height. For simplicity and because few data exist regarding the effect of scale, the current gas phase model assumes that the combustion properties are invariant with scale over the range of interest.

Solid Phase Model: The model we are investigating (Atreya, 1983) treats the solid as an opaque, one-dimensional, locally reacting body, with finite thickness and density-dependent thermal properties. The local density is determined by a first order Arrhenius reaction. Gasification products from any location within the solid are assumed to be transported instantaneously to the exterior of the solid.

The governing equation is basically the heat conduction equation with the addition of the following source/sink term:

$$\frac{\partial \rho_s}{\partial t} \left[\Delta H_v - C(T - T_o) \right] \qquad \text{(1)}$$

where ρ_s is the density of the solid, t is time, ΔH_v is the heat of pyrolysis, C is a constant comprising the specific heats and densities of the virgin, char, and volatile materials, T is the temperature of the solid, and T_o is the initial temperature of the solid. Note that the heat of pyrolysis term (the first term) in the bracket is an energy sink, whereas the second term is an energy source. Consequently, a net exothermic condition occurs when T reaches a certain level (about 400°C for the current calculations in which the heat of pyrolysis was 125 kJ/kg).

Figure 1 shows the results of gasification calculations made with this model. The solid curve was generated using a value of C = 0.37, which was determined from typical values of wood, char, and volatile properties. The second peak on this curve is larger and the time scale is shorter than expected from experiment. The dotted curve in the figure is closer to what is observed experimentally. The latter curve was generated by setting C = 0, which is equivalent to assuming that the enthalpy carried away by the volatiles is equal to that gained as a result of change from the solid to the char material. Although this is not a valid assumption, the results illustrate that the second peak is very sensitive to the physical properties of the components. Other calculations have shown that the second peak is sensitive to the rear-face boundary condition.

Currently we are assessing these and other sensitivities with the intent of reporting our findings as part of this presentation.
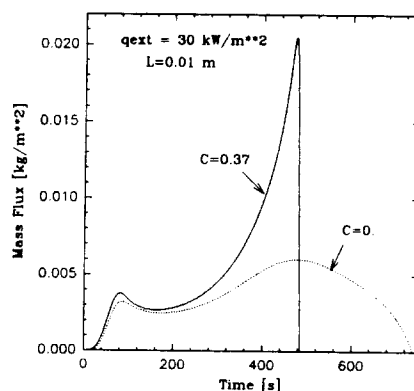

Figure 1. Calculated gasification rates

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